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Early Development

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ABSTRACT: Long-term economic development involves four fundamental processes: the exploitation of increasing returns to specialization, the transition from household to market production, knowledge and human capital accumulation, and industrialization. In this paper, we integrate these processes into a coherent framework for thinking about economic history. Pre-industrial development is driven by increasing returns to specialization made possible by a growing population. Increasing specialization eventually activates a learning technology and initiates industrial growth, which carries the economy to a fully market-based balanced-growth path. Among other things, we attribute a role to population and market size that is consistent with the evidence.

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Economic growth since the Industrial Revolution has been truly remarkable. Angus Maddison (1982) estimated, for a sample of sixteen industrialized countries, that total product increased sixty-fold and per capita product rose thirteen-fold since 1820.[1] This extraordinary performance is even better appreciated by contrasting it with prior historical experience. Table 1, also from Maddison, presents population and per capita product growth rates since 500 AD. Although the numbers are highly aggregated both across countries and over time, and are obviously imprecise, they tell a dramatic story.

For the thousand years following the fall of Rome, there was little net progress in population and none in per capita product. From 1500 to 1700, progress was also very poor, although population growth doubled and per capita product began to grow slightly.[2] The period from 1700 to 1820 was marked by a doubling of both population and per capita product growth compared to the preceding two hundred years, although per capita growth was still very poor by today's standards.[3]

Improvement in transportation, particularly during the latter period, helped break down the isolation of self-sufficient villages and greatly increased the scope for economies of scale and specialization. Such progress prompted Adam Smith (1776) to observe that productivity gains were made possible by the division of labor, which in turn was limited by the extent of the market. In his day, markets grew not only because of rising population, but also because improved transportation greatly enlarged regional markets for many goods and services.

From 1820 to 1980 population growth again more than doubled compared to the previous hundred and twenty years. This time, however, growth in per capita product increased eight-fold, reflecting the startling jump in technological improvement and productivity growth associated with industrialization.

The rise of urban population in Europe indicates the extent to which specialization associated with the division of labor accompanied economic development. For towns of five thousand or more, Paul Bairoch (1988) estimates urban population in 1000 AD. at about 10% of the total, rising only slightly to 12% by 1700. Urbanization quickened over the next hundred and

Table 1 – Performance Characteristics of Four Eras

Era	Average Annual Compound Growth Rates	
	Population	Per Capita GDP
500-1500	0.1	0.0
1500-1700	0.2	0.1
1700-1820	0.4	0.2
1820-1980	0.9	1.6

Source: Maddison (1982), Table 1.2, p.6. The sample includes sixteen countries, twelve from Europe, plus Australia, Canada, Japan, and the U.S.A.

fifty years with urban population rising to 19% of the total by 1850. But the pace exploded after that, bringing urban population to 67% of the total by 1980.[4] The trend in city dwelling thus mirrors the growth in population and per capita product over the same long history.

In the late 1700s and early 1800s there occurred the great break with the past that we call the Industrial Revolution. The Industrial Revolution was marked by a widespread systematic application of empirical knowledge and methods to the production of goods and services. Attempting to understand the onset of industrialization, David Landes (1969) pointed out that many technical improvements became feasible only after advances in associated fields. The steam engine is the classic example of this. In the 1800s, know-how associated with the division of labor had progressed sufficiently that the search for technological improvements became routine and productive. Widespread innovation, in turn, created more specialized knowledge which further raised the productivity of time devoted to innovation. In this way, the Industrial Revolution initiated the cumulative, self-sustaining, technical improvements that give rise to modern economic growth.

Our paper presents a model motivated by the broad picture of early development described above. The history of our model economy spans three epochs separated by two great transitions: a pre-market period prior to the appearance of cities, pre-industrial market development prior to the Industrial Revolution, and industrial growth since. Population is initially too small to support a market sector. But if the population continues to grow, the market sector eventually opens. This first transition corresponds to the initial formation of cities, perhaps five or six thousand years ago [Bairoch (1988), Part 1]. The model then generates a long pre-industrial period in which growth in per capita product is tied to population growth. This is followed by an Industrial Revolution, after which productivity grows endogenously regardless of the growth of population.[5]

In the model, per capita product grows as production shifts from primitive processes to market-based specialized techniques. The model economy is slow to specialize in the pre-industrial period if the population grows slowly, reflecting the relatively slow pace of urbanization prior to the Industrial Revolution. But thereafter, the pace of modernization quickens, reflecting the rapid urbanization that accompanied industrialization.

Each household in our model is endowed with a *primitive*, diminishing-returns technology allowing it to produce its own consumption goods. A purely primitive economy is one in which all goods production is carried out by each household independently using this technology. There is also a *market* technology that exhibits increasing returns due to specialization along the lines of Paul Romer (1987, 1990).[6]

Once the market sector has opened, continuing population growth enables the economy to benefit more fully from increasing returns. The growing population raises market sector wages and lowers the primitive sector marginal product, thereby causing the market sector to expand at the expense of the primitive sector. Our model thus reproduces the stylized fact emphasized by Luis Locay (1990) that production shifts from households to firms as the economy develops. It also embodies Smith's (1776) idea that the division of labor is limited by the extent of the market. Population is the scale factor governing the size of the market in the pre-industrial period, although we recognize that other factors, such as transportation costs, also help determine market size.

Productivity gains during the pre-industrial period arise primarily from an ever-finer division of labor without much improvement in fundamental productive techniques themselves. The pre-industrial period in our model economy is one in which households choose to remain in a "no-learning corner" in the sense that they devote no time to devising fundamental improvements in technology. They choose not to innovate because learning productivity depends on the economy-wide degree of specialization, and initially the specialized market sector is too small to make learning productive. The idea is that innovation involves problem solving which, in turn, is facilitated by access to specialized tools and techniques.

An Industrial Revolution occurs in our model when the growing population expands the specialized market sector to the point where households finally choose to leave the no-learning corner. Thus, we associate industrialization with learning that yields fundamental improvements in technology.[7] We do not have physical capital in our model. Instead we index the state of technological know-how by the stock of human capital. The accumulation of human capital initiated by the Industrial Revolution enables endogenous per capita productivity growth to take place independently of the population growth rate, and greatly speeds the transition from primitive to market-based production techniques.

When the transition is complete the economy attains a path, consistent with the stylized facts of modern growth [see Nicholas Kaldor (1961) and Romer (1989)], along which time allocations are constant and per capita product grows at a constant rate. This is more familiar territory, given the work of Hirofumi Uzawa (1965), Robert E. Lucas (1988), and Sergio Rebelo (1991) among others, though the engine of endogenous growth in our model closely resembles that in Romer (1987).

Conditions for industrialization have recently been studied in three important papers. Kevin Murphy, Andrei Shleifer, and Robert Vishny (1989) show how a backward economy could raise per capita product by coordinating investment in a big push. Gary S. Becker, Murphy, and Robert Tamura (1990) produce a model with two kinds of equilibria: a "Malthusian" one with large families, little human capital, and no growth, and a "Development" equilibrium with small families and rising living standards. A development trap is also present in the paper by Costas Azariadis and Allan Drazen (1990). All three papers are primarily concerned with the possibility of multiple steady states and how this might account for observed differences across countries. We, however, focus on explaining how a long period of slow pre-industrial development eventually triggers an Industrial Revolution that leads to modern balanced growth.

We recognize that a population-driven model of development such as ours must confront a puzzle. How can a model that relies on increasing returns to labor be consistent with the lack of evidence that per capita product rises with population? And how can such a model explain why some of the world's most populous countries have such low per capita income?

Two features of our model allow us to address this population puzzle. First, scale in the sense of a sufficiently large population (or market size) is a necessary pre-condition for industrial growth. But human capital, not more bodies, is the decisive scale factor during industrial growth.

Second, per capita product can differ enormously among countries depending on the relative sizes of their primitive and market sectors. Since the timing of the Industrial Revolution does not depend entirely on population, but also involves the three technologies — primitive, market, and learning — more heavily populated countries need not pass through the transition most quickly.

To sum up, ours is a model in which population growth is advantageous primarily because of its effect on the timing of the switch to industrial growth, not because of its direct effect on per capita product growth. Think of a race in which participants must first crawl 1,000 meters and then get into race cars. A racer who is 1% faster at crawling will be about 1% farther ahead in the first phase of the race (pre-industrial growth). Once at least one racer has begun to drive (industrialize), however, small differences in the rates of crawl will lead to huge differences in relative positions.

The plan of the paper is as follows. The market-based production function is derived in Section I. The technology for accumulating human capital is motivated and described in Section II; and Section III presents the primitive technology. We then study early development, first without human capital accumulation in Section IV, and then with learning in Section V, where we discuss the timing of the Industrial Revolution. The population puzzle is discussed in Section VI, and a brief summary concludes the paper.

I. Market Production With Specialized Inputs

Market-based final good production uses labor and intermediate goods as follows:

$$Y = \left(e_Y hN\right)^{1-\alpha} \int_0^M \left[x(i)\right]^\alpha \, di \;, \tag{1}$$

where $0 < \alpha < 1$. There are N workers in the economy each of whom possesses human capital h and devotes a fraction of time e_Y to the production of final goods. Total effective work effort engaged in final goods production is thus $e_Y h N$. The x (i) are the quantities of distinct intermediate inputs indexed by i and arranged on a continuum of measure M. Thus, M denotes the range of intermediate inputs. Our final-good technology is a straightforward extension of that in Wilfred Ethier (1982) and Romer (1987) to incorporate human capital.

We model the production of intermediate goods as in Romer (1987), except that effective labor is the primary factor instead of capital. The effective-labor cost of producing the quantity x of any intermediate good is b (x) / h. Therefore, the cost in terms of workers with the minimum human capital (h = 1) is just b (x). We assume that b (0) = 0, b (ε) > 0 for ε > 0, b´(x) > 0, and b´´(x) > 0.

The market sector must satisfy two labor-market clearing conditions. First, total work effort involved in producing intermediate goods must equal its supply:

(2) $$M \frac{b(x)}{h} = e_I N .$$

Here e_I is the fraction of time an individual devotes to intermediate-good production. Second, individual effort utilized by both final and intermediate-good firms must equal total work effort, e_M, supplied to the market sector :

(3) $$e_Y + e_I = e_M .$$

At this stage, we take e_M as given, and let firm demands allocate the total between intermediate and final-good firms.

Each final-good firm chooses labor hours and intermediate inputs to maximize profit, taking the final-good wage, w, and the final-good prices of the intermediate inputs, p_i, as given. Setting marginal products equal to relative prices and exploiting the symmetry in (1) yields:

(4) $$w = (1-\alpha)(e_Y hN)^{-\alpha} hMx^{\alpha} ,$$

(5) $$p_i = p = \alpha (e_Y hN)^{1-\alpha} x^{\alpha-1} .$$

The wage, w, is the competitively determined compensation per hour in units of the final good paid to a worker with human capital of h. Symmetry implies that the price of each intermediate good will be the same in equilibrium.

Each intermediate-good firm behaves like a monopolist, since it is aware that the demand for its product is given implicitly from (5). Taking the wage, w, as given, each firm maximizes profit,

(6) $$\Pi = px - w\frac{b(x)}{h} ,$$

by choosing x, substituting from (5) for p before undertaking the maximization.

Although each intermediate firm is a monopolist, each must earn zero profit in equilibrium. If intermediate-firm profits were positive, new firms would arise to produce additional specialized inputs: M would increase, eliminating the original profit. Setting (6) to zero, and using conditions (2) – (5), results in:

(7) $$e_Y = (1-\alpha)e_M \ ,$$

(8) $$e_I = \alpha e_M \ .$$

Using (2), (7), and (8), profit maximization and zero-profit yield:

(9) $$x\frac{b'(x)}{b(x)} = \alpha \ ,$$

which implicitly defines a constant equilibrium output level, $\tilde{x}$, for each intermediate firm.

Conditions (2) and (8) yield the following expression for M, the range of intermediate inputs or the *degree of specialization*:

(10) $$M = \alpha\frac{e_M hN}{b(\tilde{x})} \ .$$

Aggregate effective labor ($e_M h N$) is the primary determinant of M. As the market sector grows, in terms of the fraction of time worked (e_M), human capital per person (h), or the labor force (N), it becomes more and more specialized as the range of inputs that complement labor expands.

Our reduced-form production function, obtained by substituting (10) and (7)) into (1), is:

(11) $$Y = A\left(e_M hN\right)^{2-\alpha} \ ,$$

where the productivity coefficient $A \equiv \alpha\ (1-\alpha)^{1-\alpha}\ \tilde{x}^{\alpha} / b(\tilde{x})$. The function exhibits *increasing returns* to effective labor, $e_M h N$.[8]

Substituting (7) and (10) into (4) yields a reduced-form expression for the wage:[9]

(12) $$w = Ah^{2-\alpha}\left(e_M N\right)^{1-\alpha} \ .$$

An important feature of the model is that w rises with population and work effort. There is, at bottom, only one factor of production, labor augmented with human capital. All output is exhausted in compensating that factor, since $w\, e_M N = Y$.

II. Human Capital Accumulation

Individuals can accumulate human capital by allocating current time to learning. Family production of human capital depends, in part, on effective learning time, $e_L h\, n$, where e_L is time spent learning, h is human capital per person, and n is the number of family members. The productivity of learning time is enhanced by the economy-wide degree of specialization, M. Learning does not use up intermediate inputs, but it is made more productive by access to knowledge associated with the production and use of specialized inputs.[10] For this reason, we assume that the quantity of each intermediate input does not matter, but the range of such inputs does.

Household acquisition of human capital is governed by the following:

$$\dot{H} = e_L \, H^{1-\gamma} M^{\gamma} . \tag{13}$$

where $H \equiv h\, n$ is the household's stock of human capital and $0 < \gamma < 1$. The technology exhibits diminishing returns to the family's stock of human capital and the range of intermediate inputs separately.[11]

Equation (13) captures the idea that holding specialization, M, constant a household’s learning time is more productive the greater its human capital. Conversely, holding household human capital constant, learning time is more productive the greater the economy-wide degree of specialization. We assume decreasing returns to the household's stock of human capital, H, because limited human capabilities make it increasingly difficult for a household to increase its knowledge. Development, however, raises the degree of specialization and offsets the decreasing returns to accumulation, making balanced growth with human capital accumulation feasible.

Using (10) to eliminate M, we can write (13) as:

$$\dot{H} = e_L \left(hn\right)^{1-\gamma} \left(\alpha \frac{h_a n f}{b\left(\tilde{x}\right)} \right)^{\gamma} e_{Ma}{}^{\gamma} , \tag{14}$$

where f is the constant number of households in the economy, and h_a and e_{Ma} are, respectively, *economy-wide per capita averages* of human capital and hours worked in the market sector. An individual household takes h_a and e_{Ma} as given when choosing its own time allocations.

If new family members are born with the average stock of household human capital, without a family's having to incur any (time) costs of education,[12] we may write a per capita accumulation equation of the following form:

$$\dot{h} = \delta e_L h^{1-\gamma} h_a^{\gamma} , \tag{15}$$

where:

$$\delta \equiv \left[\alpha \frac{f}{b(\tilde{x})}\right]^{\gamma} e_{Ma}^{\gamma} . \tag{16}$$

Our accumulation technology is similar to Lucas's (1988, eq. 13), but differs from his in two important respects. Ours recognizes an external effect of the economy-wide average per capita human capital, h_a, on the productivity of an individual's learning time. And our δ depends on the economy-wide average time devoted to market production, e_{Ma}. Both externalities enter through the degree of specialization, M.[13]

Industrial development in our model relies on the notion that per capita human capital can grow without bound. Thus, our human capital partly represents scientific knowledge that exists outside of any individual. More than that, ours is a generalized sort of human capital that indexes the economy-wide state of practical know-how.

III. Primitive Production

Each household has a primitive technology that allows it independently to produce a final good. We assume that this output is a perfect substitute for the good produced with specialized inputs in the market sector. A household's primitive production function is:

$$Y_p = B\ln(1 + e_p n) , \tag{17}$$

where Y_p is total household primitive production of final goods, e_p is the fraction of time that each household member works in the primitive sector, and B is the productivity coefficient. The product

$e_P n$ is the total household time allocated to primitive production. We choose this technology because it exhibits diminishing returns to the labor input, and because the marginal product reaches an upper bound at $e_P = 0$. The latter property is not necessary for what follows, but is convenient since it means that the primitive sector will be abandoned in finite time.

We conceive of primitive production as applying to virtually all household activities since, at least until recently, home production utilized relatively simple and traditional techniques. For those goods produced both at home and in the market, such as agricultural products, we regard as primitive only that portion produced at home for domestic use with traditional techniques.

Three characteristics distinguish the primitive technology from the market production process. First, each household operates its own primitive process independently, whereas market processes employ workers from all households. Second, individual households are too small to use specialized inputs economically with the primitive technology. Third, human capital does not enhance labor productivity in the primitive production of goods. Only innate human capital ($h = 1$) is relevant in the primitive sector.

IV. Pre-Industrial Market Development

In this section we analyze how an economy using the primitive household technology of Section III transforms itself into a market economy using specialized intermediate inputs as described in Section I. Exogenous population growth drives the development process. Initially, population is too small to support the use of specialized intermediate inputs. Eventually, however, rising population pushes the scale of operation to a critical point, at which time the market sector becomes viable and specialized market processes come into use alongside the primitive sector. This event corresponds to the formation of cities, perhaps five to six thousand years ago. We show how ongoing population growth after that expands the market and shrinks the primitive sector until the latter is shut down altogether.

To best illustrate the role of population growth in pre-industrial development, we assume for now that conditions are such that there is no human capital accumulation ($e_L = 0$). We analyze accumulation in Section V.

The bottom curve in Figure 1 shows how, according to (12), the market sector wage depends on per capita hours worked there, e_M. The wage rises with e_M because the market sector is characterized by increasing returns to labor. Differentiating (12) shows this curve to be concave to the horizontal axis. Moreover, as population, N, grows this curve rotates upwards around the left-hand origin.

The top curve shows how, according to (17), the primitive-technology marginal product per man-hour of labor, $\partial y_P/\partial e_P = B/(e_P n + 1)$, depends on per capita hours allocated to that sector, e_P (measured from the right-hand origin). The right-hand intercept is the maximum marginal product per man / hour, B, which is independent of household size. If the market sector wage rises to B, it is optimal to shut down the primitive technology (set $e_P = 0$). It is straightforward to verify that this curve is convex to the horizontal axis. Because of diminishing returns to labor, the curve rotates down over time as the population grows.

The width of the box, $e_P + e_M$, represents an individual's allocation of work effort. Under the assumption that $e_L = 0$, this exhausts his total endowment of time, which we take to be 1.

Equilibrium requires that two conditions be satisfied. First, the market sector wage must equal the primitive sector marginal product if both e_P and e_M are positive. Second, an (e_P, e_M) allocation is an equilibrium only if an individual household has no incentive to deviate from it when taking other households' allocations as given.

Figure 1 illustrates the case where population is small enough that the primitive-sector marginal product curve lies everywhere above the market sector wage curve. When this is the case, no equilibrium exists with e_P and e_M both positive, since there is no way for the market wage to equal the primitive marginal product while e_P and e_M sum to unity.

This leaves either corner, point C or D, as a possible equilibrium. The second condition, however, is not satisfied at point D, because if all households chose $e_M = 1$ and $e_P = 0$, then the marginal product of work in the primitive sector would exceed the market-sector wage at D. Hence, an individual household, taking everyone else's allocation (and, therefore, the market wage)

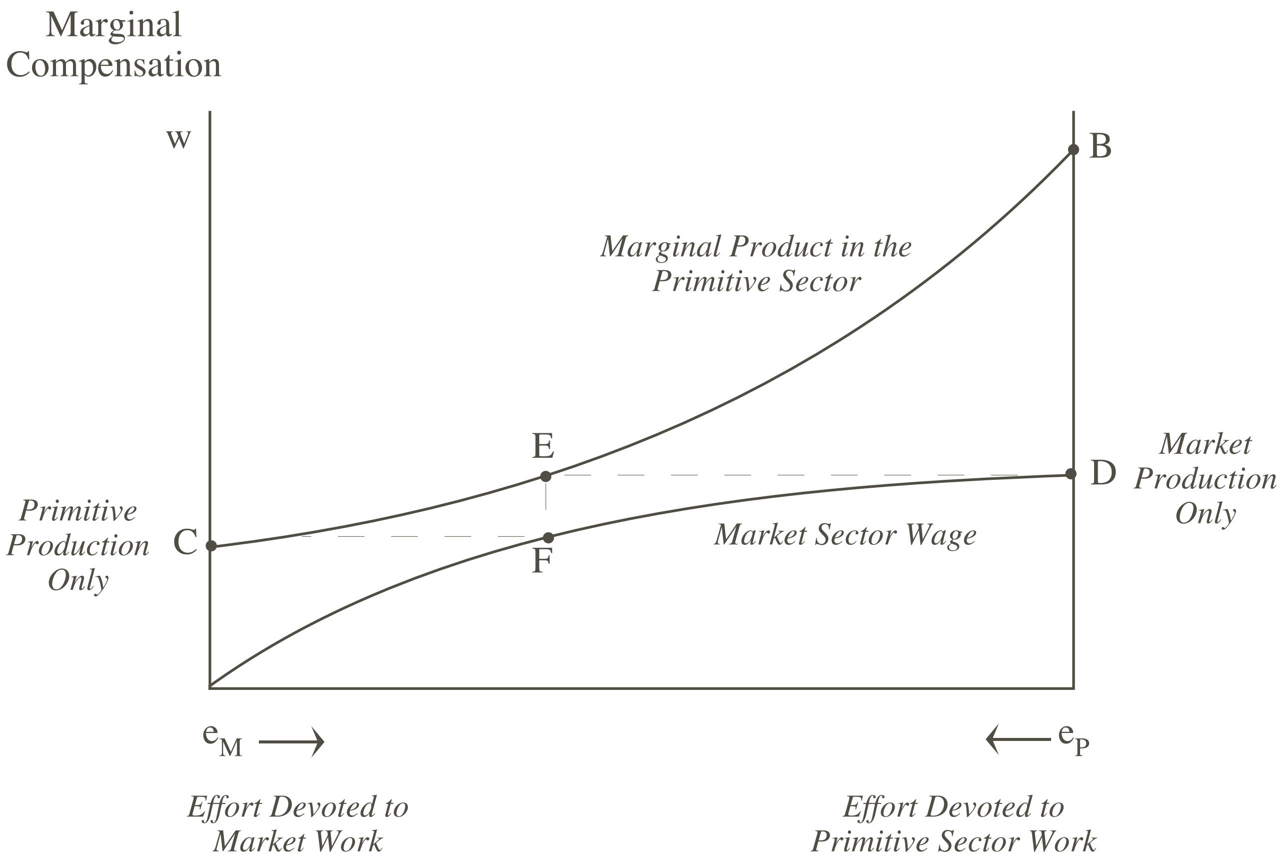

Figure 1. The Purely Primitive Economy

as given would be better off shifting work effort to its own primitive technology up to point E. If everyone did so, however, the market-sector wage would fall to point F. Repeating the argument, it is clear that point C is the only equilibrium in Figure 1. So $e_P = 1$ is the only equilibrium and the economy remains purely primitive for a sufficiently small population.

Now let population grow. This drives the upper curve down and the lower curve up until, eventually, a critical size is reached at which the two touch at a point like Z in Figure 2. This tangency point satisfies both conditions mentioned above, so it represents a *second equilibrium* in addition to the one at the $e_P = 1$ corner. Importantly, the new equilibrium at point Z can support a market sector.

Per capita consumption is higher in the interior equilibrium Z than at the corner equilibrium. To see this, note that market-sector product per person is w e_M, while primitive-sector per capita product is the area under the upper curve, measured from the right to the equilibrium e_M. Therefore, an economy-wide move from $e_M = 0$ to $e_M = e_M^z$ results in a net increase in product per person.

When the tangency appears at Z, however, the economy is at the $e_P = 1$ corner. The equilibrium will remain there if individual households believe that everyone else will not move. On the other hand, if each believes that everyone else will switch to e_M^z, then the equilibrium will jump to Z. Which equilibrium will be selected is indeterminate. Given the potential gains in current and future consumption, however, there is reason to believe that the jump would be made shortly after it became feasible. We shall, at any rate, assume that market sector springs into existence as soon as possible.[14]

Before proceeding further, note the nature of our theory of the appearance of cities. Cities are not sustainable until population rises sufficiently, because primitive technology is simply too productive relative to specialized market techniques when population is very small. Our theory is consistent with the views of Ester Boserup (1965, 1981) who argues that population pressure in early times, combined with the diminishing returns of primitive technologies, induced technological improvements associated with the establishment of cities.

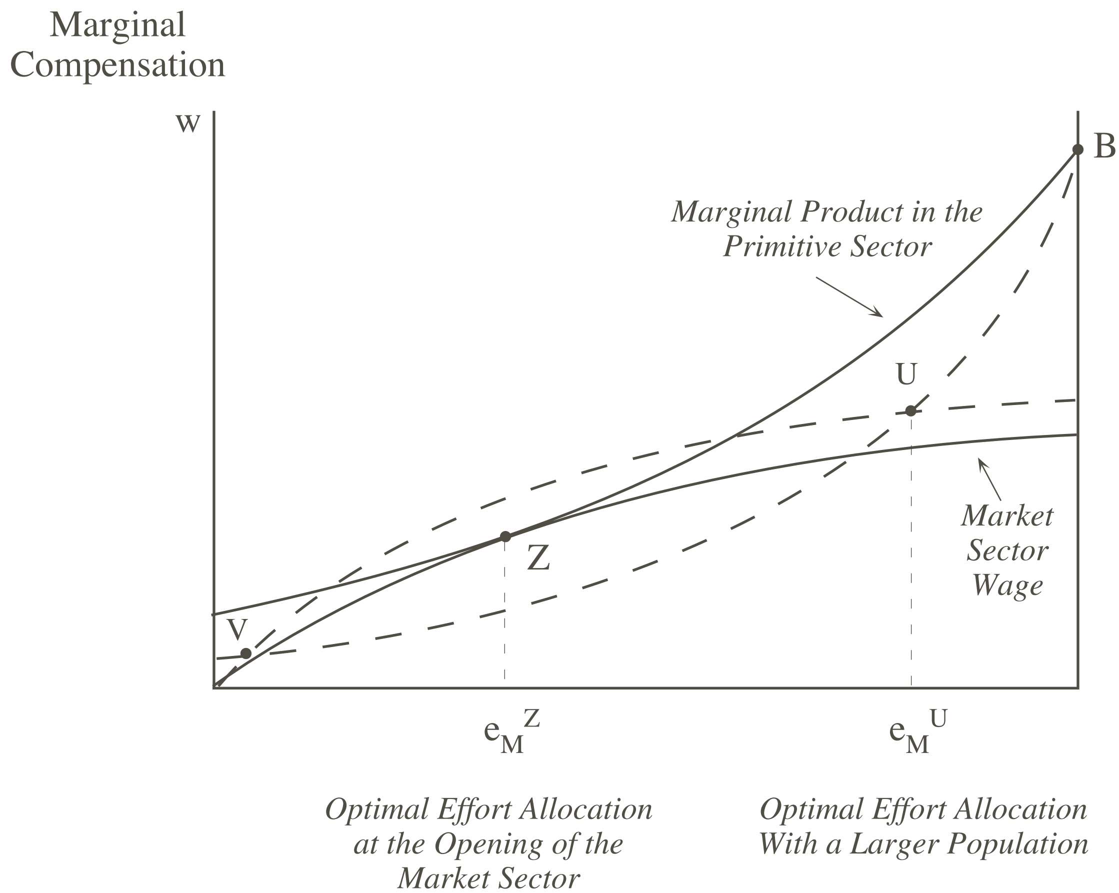

Figure 2. The Pre-Industrial Market Economy

The dashed lines in Figure 2 locate the primitive marginal product and the market wage curves for a population that has grown beyond the critical level. As one can see, the Z allocation is no longer an equilibrium with the larger population. Equilibrium is now at point U.[15] Moreover, if population continued to grow, the interior equilibrium would move to the northeast until it eventually reached B, at which time the primitive technology would be abandoned completely. Early development — the transition from a primitive economy to a fully specialized, market economy — would then be complete.

V. Industrial Development and the Transition to Modern Balanced Growth

In the previous section, development proceeded solely on the strength of increasing returns to specialization made possible by a growing population. This reflects pre-industrial growth, in which productivity gains arise from an ever-finer division of labor without much improvement in fundamental productive techniques themselves. Industrialization, on the other hand, occurs when fundamental improvements in technology come about following investment in human capital. In our model, industrialization corresponds to learning which raises the rate of technological know-how, allowing per capita product to grow without population growth. By raising the market sector wage curve in Figure 2, human capital growth speeds the transition from the primitive to the market economy. Thus, the model explains why early industrialization was associated with an acceleration of the pace of urbanization.

We pointed out in the previous section that the primitive technology would be abandoned once the rising market wage reached B. It is straightforward to show, once that happens, that the fully market economy will follow a balanced growth path along which effort allocations are constant and per capita product grows endogenously at a constant rate.[16]

Figure 3 illustrates the process by which the primitive economy attains modern balanced growth. The upper panel shows the progress of per capita product; the lower panel shows how effort is allocated between the three competing uses as development proceeds. As long as the

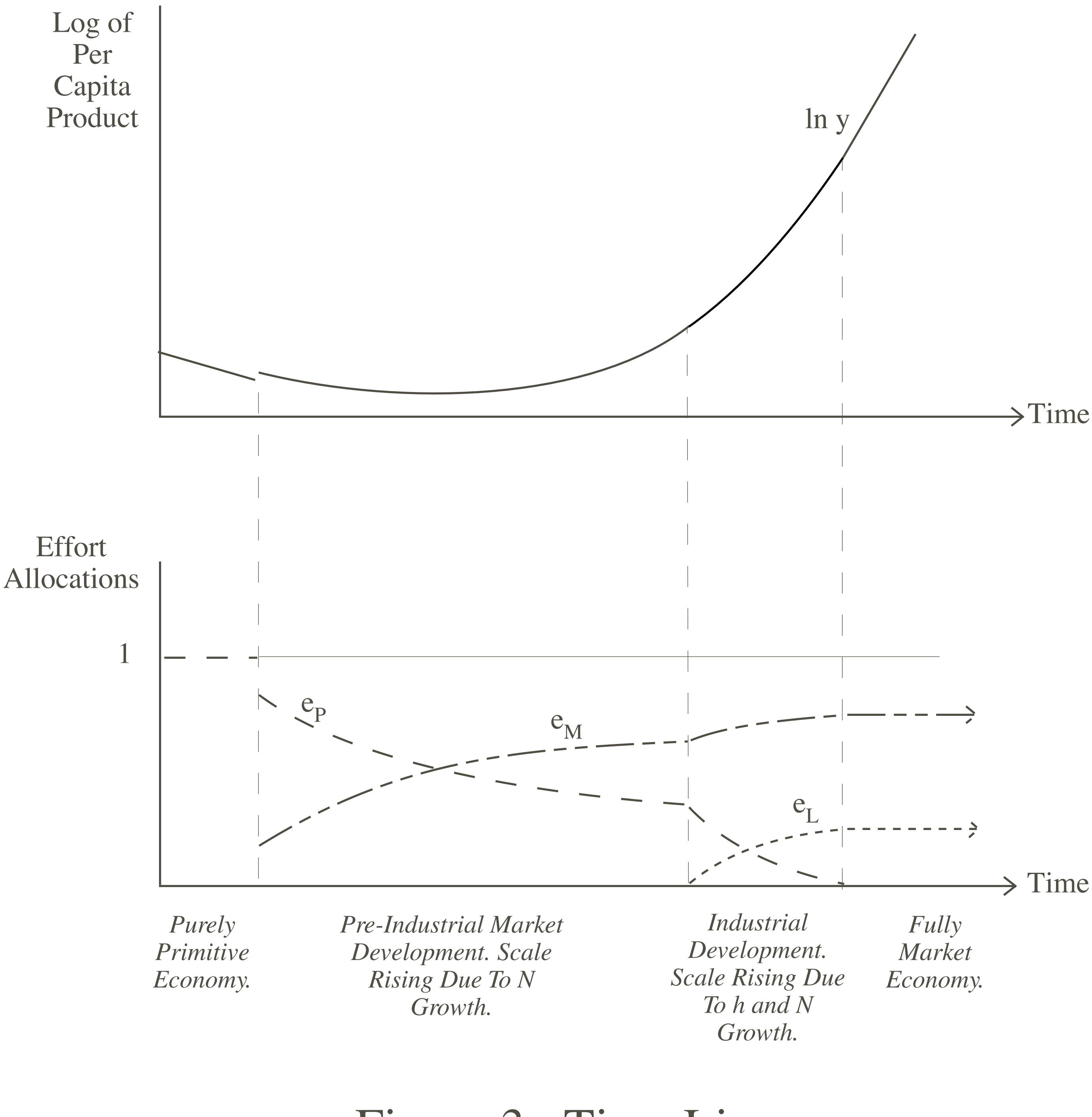

Figure 3. Time Line

economy is purely primitive, per capita product falls as the population grows.[17] There is an immediate increase in living standards at the opening of the market, i.e. urban, sector. Thereafter, effort shifts gradually from the primitive to the market sector as population continues to grow. Even as the market sector expands, however, per capita product continues to fall before it begins to rise (more on this in Section VI).

This economy will undergo an Industrial Revolution at some point prior to attaining fully modern balanced growth, if and only if:

$$\delta(1) > \rho - \eta \quad , \tag{18}$$

where ρ is the rate of time preference, η is the rate of population growth, and $\delta(1)$ refers to the value of the learning productivity coefficient in (16) when $e_{Ma} = 1$. In other words, this economy will industrialize if, at a position of no learning in modern balanced growth, the rate at which a household can transform per capita consumption intertemporally by accumulating human capital exceeds $\rho - \eta$, its net utility rate of time discount.

The Timing of the Industrial Revolution

In order to solve a forward-looking model such as this, one must always work backwards from some kind of terminal condition. As mentioned above, instead of a terminal steady state, our model has a terminal pattern of modern balanced growth. Assuming (18) is satisfied, to achieve the optimal plan households must decide when to industrialize, i.e. initiate learning, with a view to attaining the unique balanced growth path the instant the primitive technology is abandoned and the economy becomes fully modern. Because development involves the gradual transition from a diminishing returns primitive technology to an increasing returns market technology, its dynamics are fundamentally non-autonomous in population and consequently are too complex to discuss fully here. Goodfriend and McDermott (1992) contains a phase plane analysis of this economy's entire development path.

Industrialization is not an accident of history in our model; rather, it is a deliberate choice made by forward-looking, decentralized household decision makers. Households in our economy choose to fundamentally improve technology when it becomes efficient to do so. The timing of this watershed event turns on the interaction of the primitive technology, market production processes, the learning technology, population scale, and preferences.

By (16) it is feasible for households to begin to accumulate human capital through learning once the market sector opens, but they will not do so. Human capital benefits individuals in our model by raising the wage that they earn in the market sector. The wage can be expressed as the product of an individual's human capital and a *base wage*, i.e. $w = w_b h$, where the base wage,

$$w_b = A\left(e_{Ma} h_a N\right)^{1-\alpha} , \tag{19}$$

is the wage an individual would command if he had only 1 unit of human capital, given that the economy average is $h_a \geq 1$ and average hours worked in the market sector is e_{Ma}. Since the base wage is beyond the individual's control, accumulating an additional unit of human capital raises his wage in direct proportion.[18]

A marginal increase in human capital raises an individual's market sector earnings by the present discounted value of future increments, $w_b e_M$. In the early market period, few hours are worked in the market sector, per capita human capital is unity, and population is small. Hence the base wage is very low and the marginal consumption benefit to human capital is also low.

An individual's consumption opportunity cost of accumulating a unit of human capital is the time cost, $1/h\delta(e_{Ma})$, multiplied by the wage, $w_b h$; i. e., $w_b/\delta(e_{Ma})$. Thus, both the benefit and the cost of learning depend positively on the base wage and, as a first approximation, we can ignore the marginal effect of w_b on the benefit net of cost. In the early market period, however, we are left with a benefit that is low relative to the cost because few hours are worked in the market sector, and because the small size of the market sector restricts specialization, keeping learning productivity $\delta(e_{Ma})$ down.

In an equilibrium with representative agents, an individual's work effort, e_M, equals the average value, e_{Ma}. A sufficiently small $e_M = e_{Ma}$ makes it inefficient to accumulate from the start.

Accumulation becomes efficient only when market work effort becomes large enough that the present discounted value of the increments to future earnings exceeds the opportunity cost of the learning time needed to accumulate human capital.

Several factors govern the timing of the Industrial Revolution and the speed with which a society makes its transition from a primitive to a market economy. Using Figure 2 to analyze the pre-industrial period, we see that faster population growth causes the market sector to open sooner and speeds development thereafter. It is also apparent that the market sector opens later, the more productive the primitive technology (the higher is B) and the less productive the market sector (the lower is A). Likewise, development proceeds more slowly when the primitive technology exhibits smaller diminishing returns and the market sector is characterized by smaller increasing returns. The slower development of the market sector, in turn, limits learning productivity $\delta(e_{Ma})$ and delays industrialization.

These factors are not necessarily independent. For example, rapid population growth early on may be associated with a highly productive primitive technology, a high B. If population growth depends on the technology in this manner, there is little reason to expect a heavily populated region to have developed rapidly, since its highly productive primitive technology would have discouraged development of a market sector.

Our model suggests that different development experiences may be due to different geographical initial conditions. To interpret different experiences in terms of our model, we would need to understand how geographical factors account for differences in population growth, primitive technologies, early market techniques, and learning productivities. We believe that the primitive technology is critical in this, since it provides the foundation for population growth and the specialized goods that arise initially.

VI. The Population Puzzle

Population plays a central role in our model of early development. It must grow to a threshold level before the economy can support an urban-market sector, and must attain a second critical level before industrialization can begin. If population were to stop growing prior to triggering industrialization, development would cease.

Yet empirically, the relationship between population and per capita product appears weak. Consider, for example, Kuznets's (1973, pp. 41 - 48) post-War cross-country evidence from a sample of 63 developed and less-developed countries. He finds a statistically significant negative correlation between population growth and growth in per capita product. But this negative correlation is due entirely to the differences between the two groups of countries. Disaggregating, he finds that the correlation becomes insignificant both for the developed group by itself and the less-developed countries taken by themselves.

The negative correlation between groups arises because all high income countries have gone through a transition from high fertility and mortality rates to low rates, due to improved health care and the higher opportunity cost of having children.[19] Thus, the higher income growth appears to be the result of a high level of economic development, rather than a lower population growth rate. Controlling for the level of economic development, Kuznets finds little correlation between growth in population and growth in per capita product.

Since our model relies on increasing returns to population in the market sector, it would seem to imply that the most populous countries should have the highest per capita product. Yet this does not appear to be the case. Moreover, we must reconcile the central role of population in our model with evidence that finds little correlation between population growth and per capita output growth for either developed or less-developed countries.

Developed Countries

The increasing importance of human capital following the Industrial Revolution provides some resolution of the population puzzle. The accumulation of human capital means that population eventually becomes relatively unimportant for per capita product in fully developed economies. To see this, use (11) to express per capita product in a fully market economy as:

$$y = A\left(e_M h\right)^{2-\alpha} N^{1-\alpha} . \tag{20}$$

Our model of increasing returns to specialization requires that $1-\alpha > 0$, no matter how small. In fact, a small value for $1-\alpha$ is reasonable, since it makes for a longer transition to modern balanced growth. If so, then (20) shows that we would not expect per capita product in a fully market economy to be very sensitive to population. In contrast, per capita output would be approximately *proportional* to both e_M and h if $1-\alpha$ were near zero. The fraction of time spent working is constant in balanced growth and one would not expect it to be a major source of differences among national product levels. But the stock of human capital is unbounded, and can potentially account for large discrepancies across countries. Hence, our model implies that human capital per capita, rather than population, accounts for the diversity of per capita product across developed nations. The model attributes differences in levels of h, in turn, to the fact that countries have industrialized at different times, for reasons outlined in the last section.

As it stands, the model implies a positive but weak relationship between population growth and per capita product growth. The direction of effect becomes ambiguous if the model is modified to require a time cost to educate the newly born by subtracting the rate of population growth, η, from the right-hand side of (15). In that case, as in Rebelo (1992), there would be a negative effect on endogenous growth due to the fact that a higher rate of population growth requires a higher saving (learning) rate to maintain a given growth rate of per capita product.

Less-Developed Countries

The continuing widespread use of primitive production processes alongside relatively modern techniques is the most striking feature of less-developed countries (LDCs).[20] In Figure 4 we see that the effect of population on per capita product is ambiguous for an economy that is still largely primitive. The dark curves there determine an equilibrium at point G, so that per capita output is the area under HGB. The dashed curves depict the situation after a period of population growth. The equilibrium has moved to point I, where per capita product is now the area under JIB. The net change in per capita output is JKGH less KBI. As drawn, per capita product falls slightly; although it could have risen starting from a different (e_M, e_P) allocation.

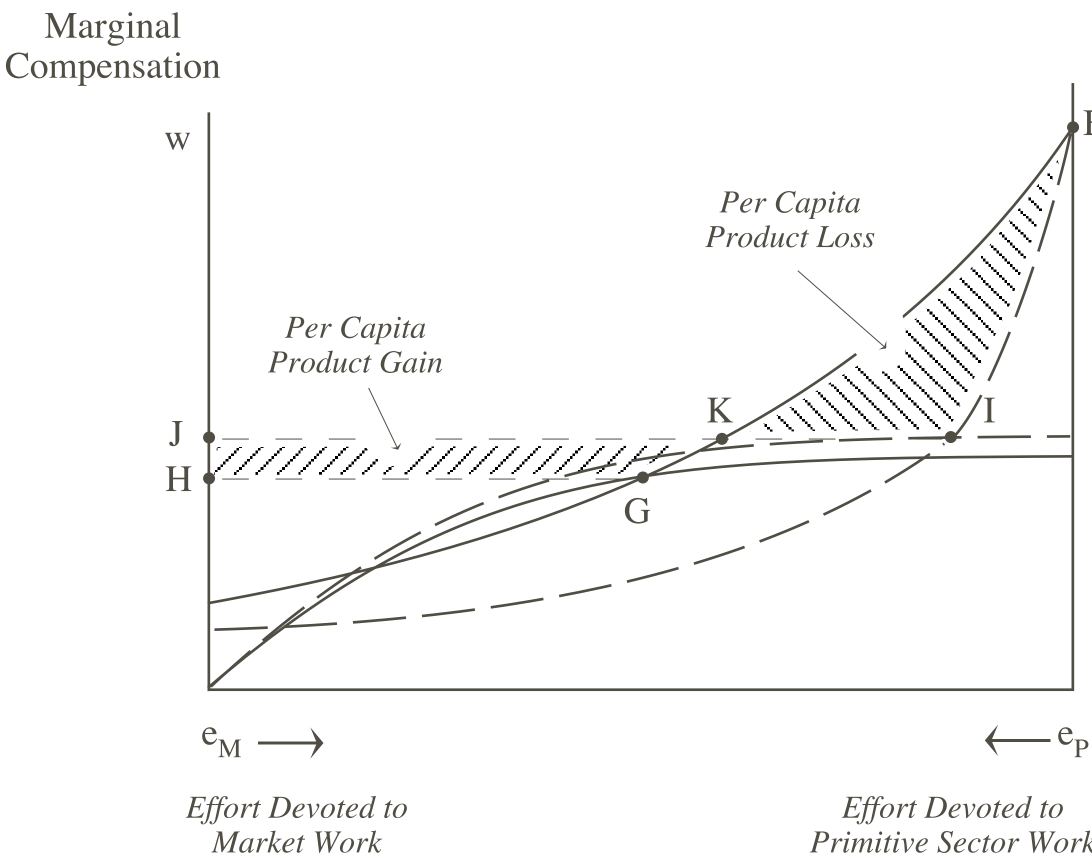

Figure 4. Per Capita Product During the Transition

Population growth can reduce the standard of living in LDCs because per capita product is the *average* of output from a diminishing returns primitive technology and an increasing returns market sector. Rising population forces down per capita product in the primitive sector. Although per capita product in the market sector rises with population, N, the increase is slight if $1 - \alpha$ is near zero. Effort shifts to the market sector in response to the higher population, but the returns to e_M there may not be high enough to offset the diminishing returns in the primitive sector. The effect of a population increase on per capita product is more likely to be negative the larger the primitive sector, the larger the diminishing returns in the primitive sector, and the smaller the increasing returns in the market sector.

Even though population growth may reduce per capita product temporarily in our model, the cumulative effect of population during the entire transition to a fully market economy must be positive. A related point is that per capita product may be considerably higher for countries at or near the end of the transition, than for countries whose primitive sectors are still relatively large. Countries that continue to produce a relatively large share of output with primitive techniques will have low per capita product regardless of population size.

Our model reconciles two apparently contradictory notions about the influence of population in LDCs. It emphasizes the role of population in driving the transition from a primitive society to a market economy. But it also allows for the possibility that population growth could actually reduce per capita product during the transition. Thus, our model explains how population growth might appear detrimental to LDC development over some periods. The link between population and per capita product is, of course, weakened further by industrialization. An increase in human capital raises per capita product in LDCs because it raises the market wage without shifting the primitive sector marginal product curve.

Taking a long, historical perspective, there is a U-shaped curve for per capita product as a function of population (or time, assuming population is growing steadily) in the pre-industrial era. This is shown in the time line of Figure 3. The U-shaped path for per capita product has two important implications. First, the path could conceivably dip below a minimum subsistence level, precluding further population growth. A binding subsistence constraint in the pre-industrial period would leave the economy in a Malthusian trap in which development would cease. Second, the effect on per capita product of an exogenous population shock due to war or plague, for example, would depend on the society's position along this curve when the shock occurred. The model implies that a plague in a relatively primitive society would raise output per person, even though it would reduce it in a largely urbanized economy. The pre-industrial data summarized in the introduction suggests that population raised per capita product after 1500 but had little effect prior to that date.

VII. Conclusion

Long-term economic development involves four fundamental processes: the exploitation of increasing returns to specialization, the transition from household to market production, knowledge and human capital accumulation, and industrialization. In this paper, we integrated these processes into a coherent framework for thinking about economic history.

The main propositions found in our paper are these:

(1) Population must grow to a threshold before our economy can support an urban-market sector. After this sector appears, rising population continues to shift effort from the household to the market sector because the latter is more efficient at larger scales of operation. The pace of urbanization is dictated by the rate of population growth in the pre-industrial economy.

(2) Population must attain a second critical level to get industrial growth going. The human capital or knowledge accumulation that characterizes modern industrial growth does not begin until market size has expanded the range of specialized goods sufficiently to make routine innovation worthwhile. Market size, perhaps through trade, is a necessary precondition for industrialization.

(3) Two recently proposed "growth engines" – human capital and increasing returns to specialization – are compatible so that human capital, not more bodies, is the decisive

factor during industrial growth. Increasing returns to scale in pre-industrial development are consistent with the achievement of a fully modern balanced growth path along which per capita product grows at a constant endogenous rate, regardless of population growth.

(4) Population may increase or decrease per capita product in our model, depending on the relative size of the primitive and market sectors. The reason is that per capita product is an average of output from a diminishing returns primitive technology and an increasing returns market technology. This insight helps explain how population growth can be viewed as good for per capita product in some contexts, for example, 18th century Great Britain and 19th century United States, and bad in others, such as modern-day China and India.

(5) Ours is a model in which population growth is advantageous primarily because of its effect on the timing of the switch to industrial growth, not because of its direct effect on per capita product growth. Faster population growth makes industrialization begin sooner by speeding the transition from household to specialized market production processes. A more productive primitive technology slows the transition and delays industrialization. When faster population growth is associated with a more productive primitive technology, however, the net effect on the timing of the switch to industrial growth is uncertain.

(6) The hallmark of first-generation endogenous growth models is their ability to generate perpetual growth in per capita product. The *level* of the output path, however, is largely determined by initial conditions for the relevant capital stock variables. Focusing on modern economic growth, rather than on long-term economic development, as they do, first-generation models have been silent on initial conditions. Our model, in contrast, focuses on the historical preconditions that give rise to fully modern growth. It shows that different levels of per capita product in fully modern economies are due, in part, to primitive geographical initial conditions, since these help

determine the timing of the switch to industrial growth and, thereby, the per capita human capital that a country inherits from its past.

Our closed-economy model necessarily identifies pre-industrial market size with population. In subsequent research [Goodfriend and McDermott (1993)], we analyze trade by building regional labor market segmentation and transport costs into the model. Trade allows even a relatively small country with access to a large world market to industrialize, although sufficient local population is still necessary to support a market sector that can take advantage of trade. In the open-economy model, regions may industrialize at different times because of variations in local market size or varying proximity to world markets. However, population still determines global market size and world population must still reach a critical scale before industrialization occurs somewhere in the world.

Appendix: Household Maximization and Modern Balanced Growth

A household maximizes:

(A1) $$\int_0^{\infty} n(t)\ln c(t)e^{-\rho t}\,dt \quad ,$$

where c is per capita consumption and family size n grows at rate η, by choosing effort allocations $e_M(t)$ and $e_L(t)$, subject to the time constraint:

(A2) $$e_M + e_L = 1 \quad ,$$

and the budget constraint,

(A3) $$c = w_b h e_M \ .$$

The household takes as given the path of the base wage, w_b as expressed in (19) in the text, but the wage that each member earns, $w = w_b h$, depends on his own human capital.

A household saves by allocating time to learning. Human capital accumulation is governed by (15) and (16). The productivity of learning time, e_L, depends on the economy-wide averages h_a and e_{Ma}, whose paths the household also takes as given.

Two first-order conditions are necessary for a household optimum with learning. First, the marginal utility value of e_M and e_L must be equal:

(A4) $$\frac{w_b h}{c} = q\,\delta h^{1-\gamma} h_a^{\ \gamma} \quad ,$$

where q is the shadow utility value of human capital per capita. Second, q must evolve through time according to:

(A5) $$\frac{\dot{q}}{q} = \rho - \eta - (1-\gamma)\,\delta\, e_L h^{-\gamma} h_a^{\ \gamma} - \frac{w_b\, e_M}{qc} \quad ,$$

so that the utility capital gain on human capital, plus the marginal productive value of h in learning and in enhancing wages, equals the net rate of discount. There is also a transversality condition:

(A6) $$\lim_{t \to \infty} e^{-\rho t} q(t) h(t) n(t) = 0 \ .$$

The learning technology (15) and (16) and the pricing equation (A5) govern the motion of h and q that a household optimum plan must follow. Restricting household optimum choices to equal economy-wide averages (so that $e_M = e_{Ma}$ and $h = h_a$), we can use (A2), (A3), and (A4) to eliminate e_M and e_L from the dynamic equations for h and q. The system can then be expressed in terms of a single dynamic equation in q h that satisfies aggregate consistency.

The stationary value of q h uniquely satisfies transversality (A6) and yields constant equilibrium effort allocations that generate balanced growth without transition dynamics. The equilibrium e_M allocation supporting modern balanced growth with learning is given implicitly by:

(A7) $$e_M{*} \;=\; \frac{1}{1+\gamma}\left[\gamma + \frac{\rho-\eta}{\delta\left(e_M{*}\right)}\right] \;<\; 1 \quad ,$$

where $\delta(e_M)$ is expression (16) with aggregate consistency ($e_M = e_{Ma}$) imposed. The balanced rate of growth with learning is:

(A8) $$\frac{\dot{y}}{y} \;=\; \left(2-\alpha\right)\delta\left(e_M{*}\right)e_L \;+\; \left(1-\alpha\right)\eta \;.$$

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Footnotes

[1] Maddison (1982), p. 4.

[2] Maddison notes that his estimates are below those of Simon Kuznets and David Landes, but above those of Emmanuel Le Roy Ladurie and Wilhelm Abel (Maddison, 1982, p. 7).

[3] The flat population profile before 1700 was marked by two major declines due to epidemic disease. The first occurred in the sixth and seventh centuries, the second in the fourteenth century. Such devastating epidemics had tapered off by 1700, helping to make possible the sustained growth in population that was to follow. See William McNeill (1976).

[4] Bairoch (1988), Table 13.3, p. 219.

[5] The switch from pre- to post-industrial growth in our model closely corresponds to the change from "extensive" to "intensive" growth characterized by Lloyd Reynolds (1985).

[6] Well-known discussions of specialization and the division of labor appear in George Stigler (1951) and Allyn Young (1928).

[7] Kenneth Sokoloff's (1988) analysis of patent records in early industrial America (1790 - 1846) provides evidence that the onset of industrialization was characterized by a surge in the commitment of resources to the search for advances in technology. While technological progress did not begin with industrialization (see, for example, Carlo M. Cipolla (1980)), early innovations arrived sporadically and slowly, whereas modern invention and innovation is routine and widespread.

[8] The source of increasing returns to effective labor is easily seen by rewriting (1) as $Y = [(1-\alpha)e_M h N]^{1-\alpha} M \tilde{x}^{\alpha}$. By (10), $e_M h N$ has a unit elastic effect on Y through M. Holding M constant, the elasticity of Y with respect to $e_M h N$ is $1-\alpha$; so the total elasticity is $2-\alpha$.

[9] The wage cannot be found by differentiating (11), since it is determined by small firms who do not benefit from the external effect of labor in increasing the degree of specialization.

[10] Our intermediate goods, to use Romer's (1990) terminology, are both excludable and rivalrous in final good production, but they are neither in the learning technology.

[11] We follow Uzawa (1965), Lucas (1988) and Becker, Murphy and Tamura (1990) in assuming constant returns to e_L because it simplifies the solution for time allocations in balanced growth.

[12] This assumption corresponds to adding the term ηH to (13), where η is the growth rate of family size, n.

[13] Strictly speaking, one can imagine a model in which learning involves intermediate goods but there are no external effects on learning productivity. As long as there are uncompensated learning productivity benefits associated with specialization, however, there will be external effects on learning operating through M. Since the mere exposure and routine access to specialized goods generates ideas that cannot be compensated, we think that as a practical matter the favorable effects of specialization on learning involve important external effects.

[14] Early empires appear to have used coercion and religion as coordinating devices to ensure the movement to urban areas in order to realize gains from specialization. Although important and interesting, a more complete treatment of government policy to foster urbanization, or to encourage learning, is beyond the scope of this paper.

[15] For a given population size, a point like V is also an equilibrium. We ignore such equilibria, however, since they are not stable.

[16] The effort allocations that support modern balanced growth are derived in the appendix.

[17] Anthropologists generally agree that mankind enjoyed a sort of golden age in the Upper Paleolithic period (35,000 to 10,000 BC) before the introduction of agriculture. With the extinction of certain animals after the last ice age, however, living standards fell secularly as population rose, and mankind domesticated plants and animals in an effort to restore its earlier prosperity. For an analysis along these lines, see Marvin Harris (1977) as well as Boserup (1965, 1981).

[18] The wage that an individual commands in the labor market can be written as the marginal product of effective labor in final-goods production given M, $\partial Y/\partial(e_Y h N)$, times the units of

effective labor that each hour of his time is worth, h. An individual with only the minimum human capital (h = 1) just earns $\partial Y/\partial(e_Y\, h\, N)$, the base wage, w_b. Therefore, dividing (12) by h yields the base wage.

[19] On this point, see Barro and Becker (1988) and Becker, Murphy, and Tamura (1990).

[20] See Cairncross (1962), p. 21.